The Role Played By Blocking over the Northern Hemisphere in Hurricane Katrina

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ABSTRACT: In 2005, there were 28 tropical Atlantic storms and hurricanes according to the Saffir-Simpson scale. Among these, there were three large hurricanes with surface winds of more than 150 knots: Katrina, Rita, and Wilma. This paper investigates the role played by a blocking system over the northern hemisphere in hurricane Katrina. The 6-hour and daily NCEP/NCAR reanalysis data composites for meteorological elements (surface pressure, surface wind, precipitation rate, and geopotential height at 500 mb level) over the northern hemisphere for August 2005 were used in this study. In addition, satellite images for hurricane Katrina and its damage have been used. These datasets have been analyzed using the methodology of anomalies. The results reveal that a diffluent block persisted over Siberia and was associated with a strong westerly air current aloft over North America from 22 to 31 August 2005. In addition, a strong westerly air current aloft existed over the North Atlantic region. Splitting of westerlies into two branches occurred over the North Atlantic; the first branch went towards the north while the second extended to the south towards the tropical Atlantic region. The splitting of the main air current over the North Atlantic caused an unusually strong northeast and easterly wind in the tropical Atlantic region. These unusual winds caused by the blocking system in the northern hemisphere circulated, accelerated, and controlled the track of hurricane Katrina from 23 to 31 August 2005. Analysis of the 10-day mean anomaly of the geopotential height at 500 mb for the northern hemisphere for August 2005 revealed that there was an outstanding positive anomaly of more than +200 m over North America simultaneously with positive anomalies of more than +150 m over Siberia during the last 10 days of August 2005). [The Journal of American Science. 2008; 4(2):10-25].

Keywords: Hurricane, Geopotential Height, Zonal, Meridonal, Blocking.

1. Introduction

The 2005 hurricane season will long be remembered for its tropical Atlantic storms. The season had 28 tropical Atlantic storms, including three large hurricanes with surface wind speeds of more than 150 knots: Katrina, Rita, and Wilma (NCDC, 2005). Katrina had sustained wind speeds of 150 knots, making it a Category 5 hurricane on the Saffir-Simpson scale, which is a rating scale from 1 to 5 based on a hurricane's intensity (Zebrowski and Judith, 2005). Hurricane Katrina initiated over the tropical Atlantic region on 23 August and lasted until 31 August. It caused about $60 billion in damage, displaced 500,000 people, and killed 1,053, making it the deadliest hurricane to hit the United States since 1928. Katrina made landfall at Gulfport, Mississippi, and 80% of New Orleans was inundated with water up to 20 feet deep after several levees failed around Lake Pontchartrain. Katrina shut down an estimated 95% of crude production and 88% of natural gas output in the Gulf of Mexico.

Several papers have reviewed the tropical storms and its hazards and damage, (Sallenger, 2000; Gray, 2001; Zebrowski and Judith, 2005, Asbury, 2006; Verbout et al., 2007). Many studies have also investigated the formation and persistence of hurricanes, the effect of Atlantic blocking action upon European weather and climate, and the role of blocking systems in the northern hemisphere climate variability (Rex, 1950a, 1950b, 1951; Dole, 1978, 1982; Hafez, 1997, 2003; Cohen et al., 2001; Hasanean and Hafez, 2003; Hafez, 2007). According to these studies, blocking systems form from anomalies of the geopotential height at 500 mb over the northern hemisphere of more than +100 m and that persist for at least 7 days. The present work aims to uncover the role played by blocking systems that existed over the northern hemisphere through the period 22-31 August 2005 in hurricane Katrina.

2. Data and Methodology

The 6-hour and daily NCEP/NCAR reanalysis data composites for meteorological elements (surface pressure, surface wind, precipitation rate, and geopotential height at the 500 mb level) over the northern hemisphere for August 2005 (Kalnay et al., 1996) were used in this study. In addition, satellite images for hurricane Katrina and its damage were used. Satellite images were obtained from NASA's Earth Observatory and from Jeff Schmaltz of the MODIS Land Rapid Response Team at NASA Goddard Spaceflight Center. In the present work, these datasets were analyzed using the anomalies methodology and linear correlation coefficient techniques (Spiegel, 1961).

3. Results

3.1 Study of the role played by blocking system over the northern hemisphere in Hurricane Katrina

Three violent category 5 Atlantic storms formed during the 2005 hurricane season. Hurricane Katrina initiated on 23 August and lasted until 31 August, with maximum surface winds reaching 150 knots and a minimum surface pressure of 902 mb on 28 August over the Atlantic Ocean at Lat. 26.3º N – Lon. 88.6º W. Figure 1 shows the daily GEOS satellite images for the tropical Atlantic region through the period of hurricane Katrina (22-31 August 2005), and illustrates the development stages of the hurricane. Hurricane Rita had a wind speed of 155 knots, a minimum surface pressure value of 897 mb, and lasted from 18 to 26 September. Hurricane Wilma had 160 knot surface wind speeds, a minimum surface pressure value of 882 mb, and lasted from 15 to 26 October 2005. The present work focuses mainly on hurricane Katrina. Figures 2-4 show the distribution of vector, zonal, and meridional surface winds over the tropical Atlantic region through the period of 22-31 August 2005. Figure 5 shows the daily distribution of the 500 mb geopotential height (m) composite mean in the northern hemisphere through that period. Analysis of the 10-day mean of the northern hemisphere geopotential height fields at the 500 mb level during August 2005 reveals that a diffluent block existed over Siberia through the last 10 days of August. The block over Siberia had maximum positive anomalies of +150 m in the north and minimum negative anomalies of –150 m in the south. During the last 10 days of August, a remarkable abnormal high pressure system existed over North America, with maximum anomalies of +200 m, which was accompanied by abnormal low pressure over the North Atlantic region with minimum anomalies of -200 m, as shown in Figure 6 and Table 1. Analysis of the daily mean of the northern hemisphere geopotential height anomalies at the 500 mb level for the period 22-31 August 2005 shows that the unusual pressure system over the northern hemisphere over Siberia, North America, and the North Atlantic persisted for 9 days (23 to 31 August). Table 2 illustrates the distribution of the geopotential height anomalies over the northern hemisphere though the period of study. The daily means of the anomalies of the meridional wind, zonal wind, and precipitation rate in the tropical Atlantic and America through the period of 22-31August 2005 were analyzed. The results show that the tropical Atlantic region and America were below two abnormal types of zonal and meridional winds (Figures 3 and 4). In addition, a maximum anomaly of precipitation (+90 mm/day) occurred on 29 August. The correlation coefficients between the anomalies of geopotential height over the North Atlantic and the anomalies in the meteorological elements in the tropical Atlantic and America show significant correlations (+0.75 and +0.60) between the anomalies in the geopotential height at the 500 mb level over North America and Siberia, and the precipitation rate of the tropical Atlantic and eastern America, respectively, through the period of 22-31 August 2005. In addition, there is a significant negative correlation (-0.60) between the anomalies in the geopotential height at the 500 mb level over northern Siberia and the anomalies in the meridional wind over the tropical Atlantic region and eastern America, as shown in Table 4.

22 AUG 2005 27 AUG 2005

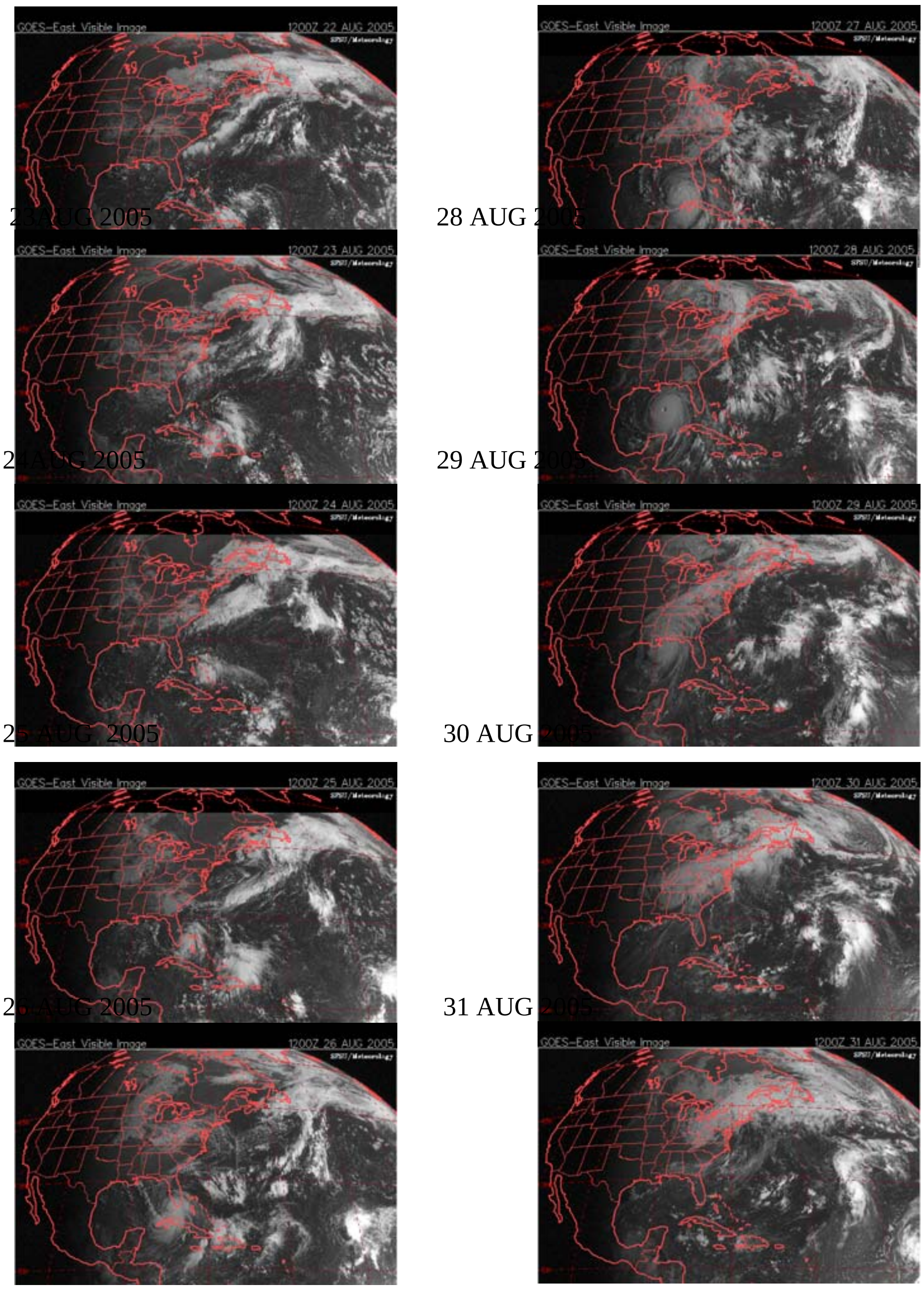

Figure (1): Daily GEOS satellite images for the tropical Atlantic region through the period of hurricane Katrina (22-31 August 2005).

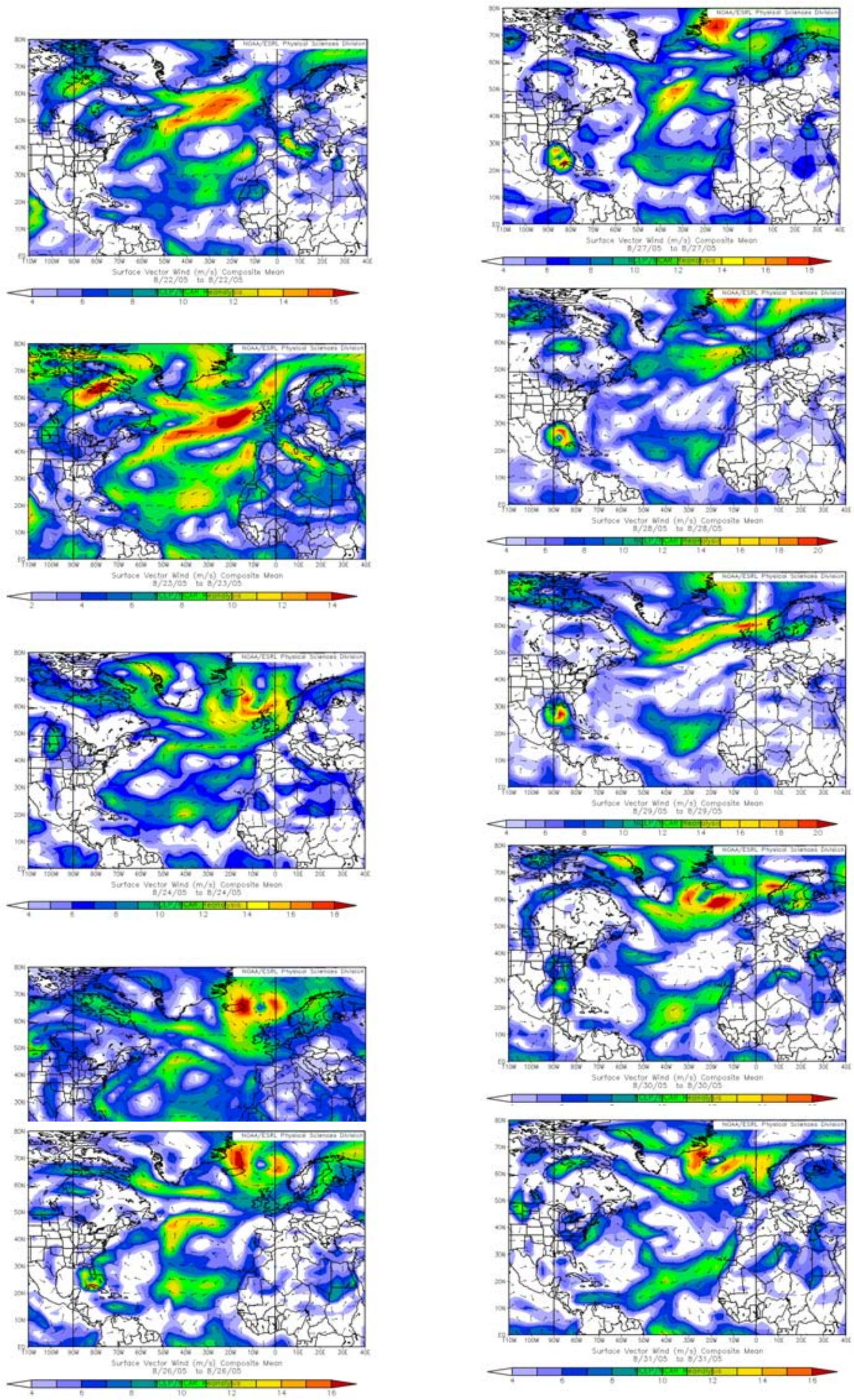

Figure (2): The daily distribution of surface wind vector (m/sec) composite mean in the North Atlantic region through the period of 22-31 August 2005.

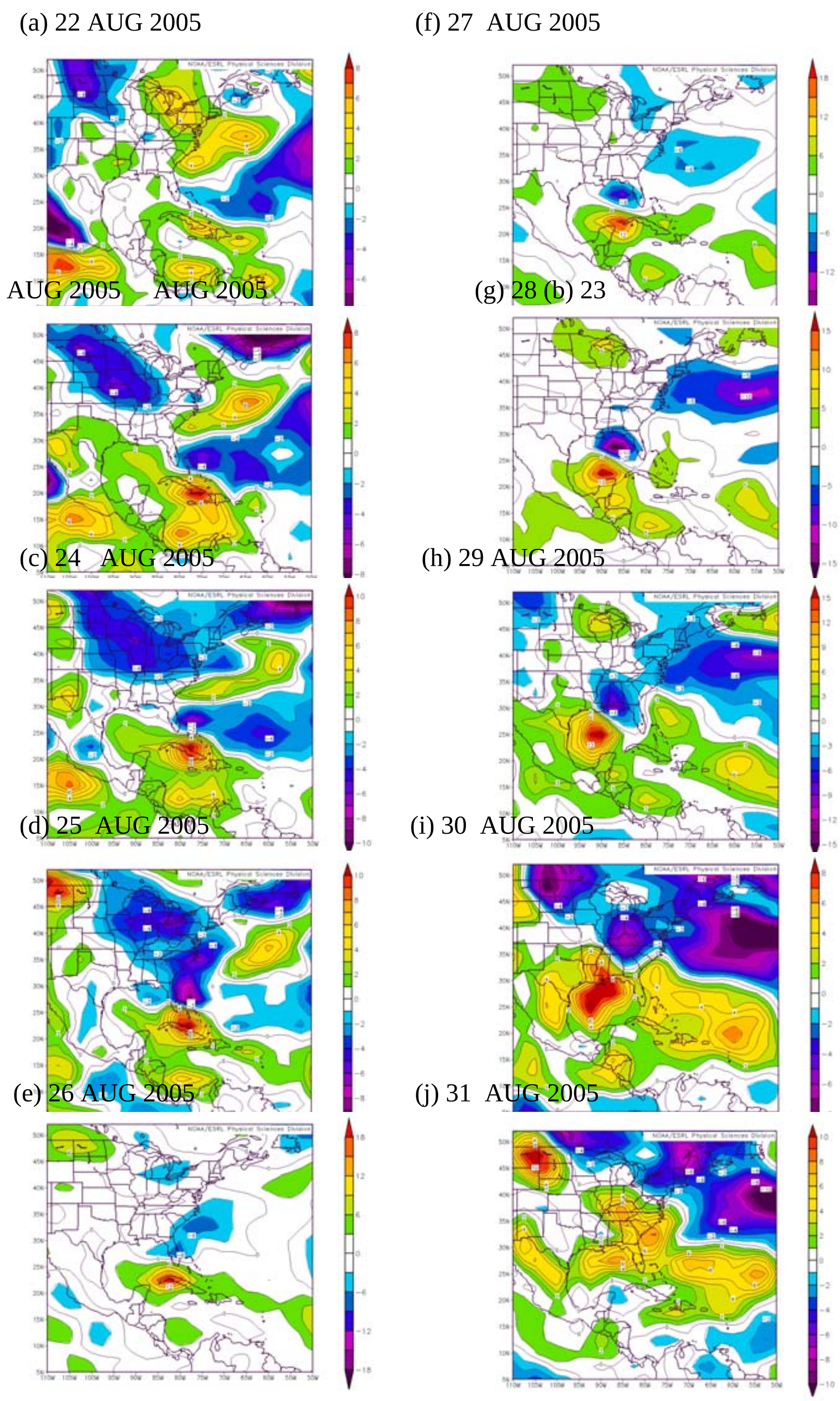

Figure 3: The daily distribution of surface zonal wind (m/sec) composite mean in the tropical Atlantic region through the period of 22-31 August 2005.

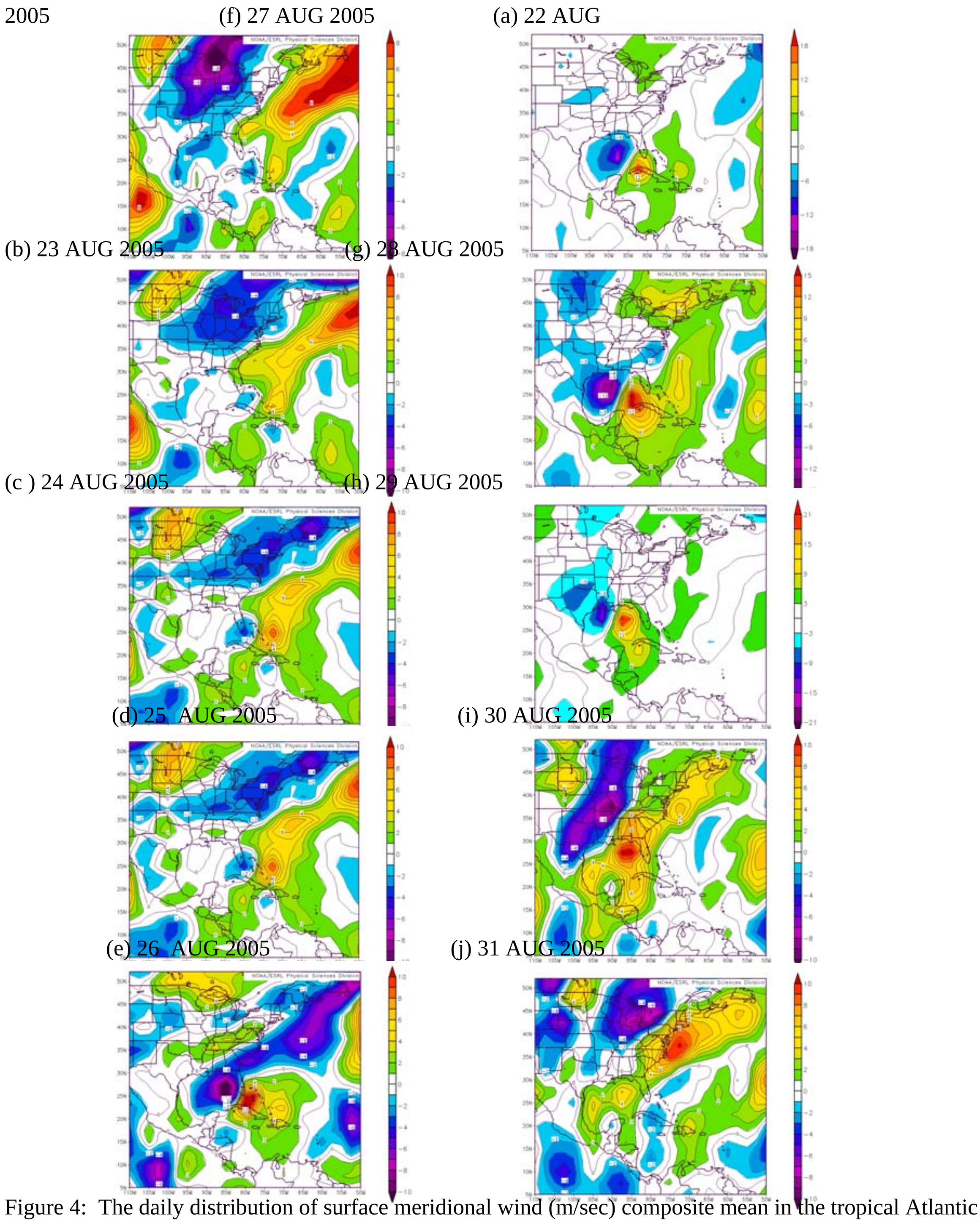

Figure 4: The daily distribution of surface meridional wind (m/sec) composite mean in the tropical Atlantic region through the period of 22-31 August 2005.

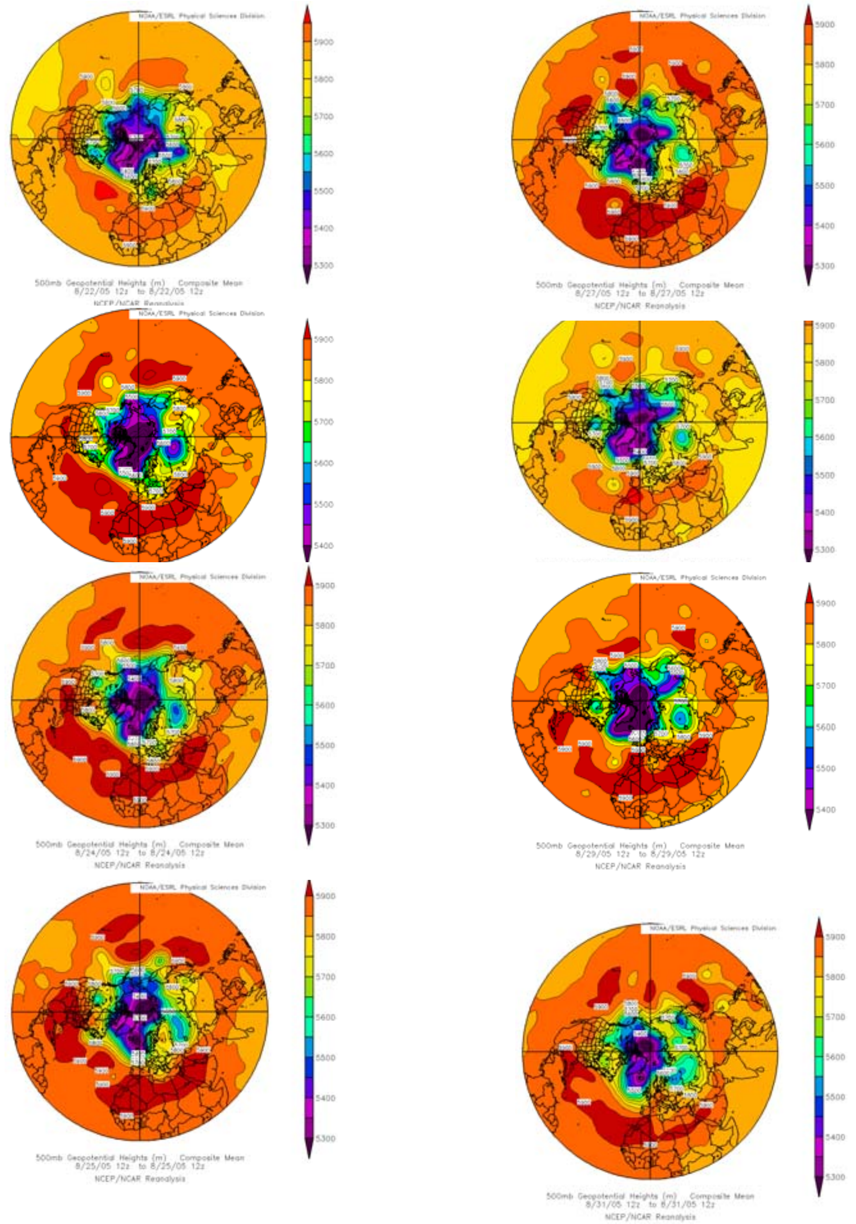

Figure 5: The daily distribution of 500 mb geopotential height (m) composite mean in the northern hemisphere through the period of 22-31 August 2005.

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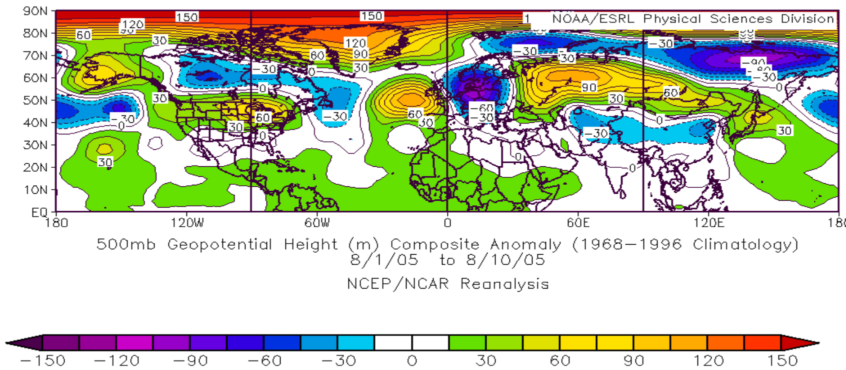

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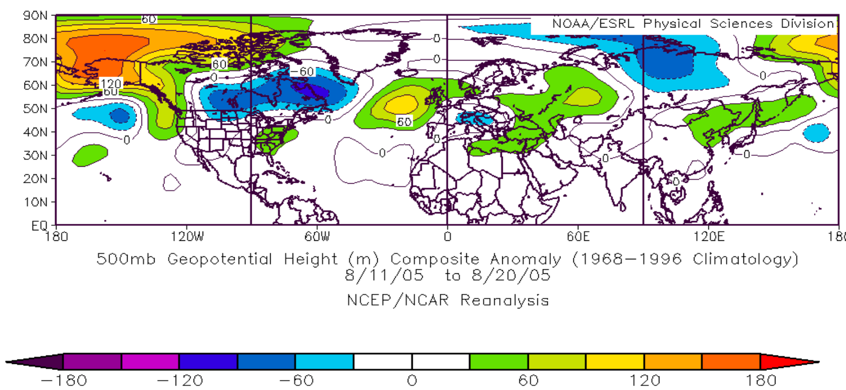

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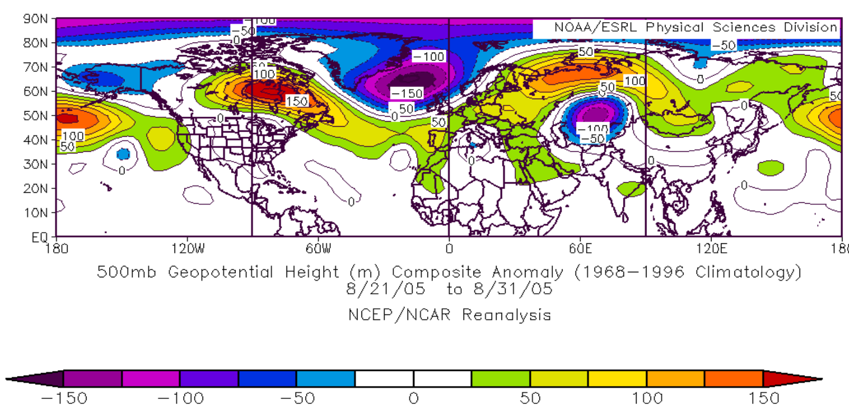


Figure 6: The 10-day distribution of the 500 mb geopotential height composite anomaly in the northern hemisphere for periods of (a) 1-10 August 2005, (b) 11-20 August 2005, and (c) 21-31 August 2005.

Table 1. The 10-day mean of the northern hemisphere geopotential height anomalies at the 500 mb level through the period of 22-31 August 2005.

Region / Time period	North America	North Atlantic	Europe	Siberia
1- 10 August 2005	+60 m	+120 m	-90 m	+ 120 m
11-20 August 2005	-120	+120	+60 - 60	+90
21-31 August 2005	+200	-200	+100	+150 -150

Table 2. The daily mean of the northern hemisphere geopotential height anomalies at the 500 mb level through the period of 22-31 August 2005.

Region / Duration Time	North America	North Atlantic	Europe	Siberia North	Siberia South
22 August 2005	+150 m	-150 m	+150 m	+150	-150 m
23 August 2005	+150	-200	+150	-150	-150
24 August 2005	+200	-250	-50	+200	-150
25 August 2005	+175	-250	-50	+250	-200
26 August 2005	+200	-200	+50	+200	-200
27 August 2005	+175	-250	+100	+250	-200
28 August 2005	+225	-200	+100	+250	-150
29 August 2005	+250	-175	+150	+250	-175
30 August 2005	+250	-250	+150	+250	-150
31 August 2005	+250	-175	+150	+250	-150

Table 3. The daily mean of anomalies of the meridional wind, zonal wind, and precipitation in the tropical Atlantic and America through the period of 22-31 August 2005.

Anomalies Duration Time	Anomalies of meridional wind (m/sec) Eastern America	North Atlantic	Anomalies of Tropical Atlantic precipitation (mm/day)	Anomalies of zonal wind (m/sec) Eastern America	North Atlantic
22 August 2005	-8	+8	+15	+6	-6
23 August 2005	-4	+10	+15	-6	+8
24 August 2005	-4	+10	+25	-8	+10
25 August 2005	-8	+8	+30	-8	+10
26 August 2005	-10	+10	+50	-6	+18
27 August 2005	-15	+18	+60	-15	+18
28 August 2005	-15	+15	+60	-15	+15
29 August 2005	-15	+21	+90	-10	+15
30 August 2005	-10	+10	+55	-6	+8
31 August 2005	-8	+10	+50	+10	+10

Table 4. The correlation coefficient matrix of the anomalies in the northern hemisphere geopotential height and the anomalies in meridional winds, zonal winds and precipitation in the tropical Atlantic region during the period of Hurricane Katrina.

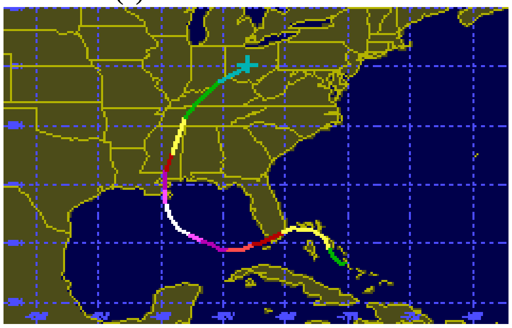
Correlation coefficient	Anomalies in the meteorological elements in regions of Tropical Atlantic (TA) and America				
Anomalies in geopotential height of region	Meridional wind over TA and eastern America	Meridional wind over north America	Precipitation in the TA and eastern America	Zonal wind over TA and eastern America	Zonal wind over north America
North America	-0.40	0.36	0.75*	0.01	0.38
North Atlantic	-0.06	0.05	0.03	0.48	-0.39
Europe	-0.30	0.29	0.28	0.30	-0.02
North Siberia	-0.60*	0.28	0.60*	-0.01	00.3
South Siberia	0.34	-0.19	-0.22	0.49	-0.53

(*): means of value with significant level > 95 %

3.2. Comparative study of Hurricanes Katrina, Rita, Wilma, and Andrew and the Blocking System in the Northern Atmosphere

To investigate the above described role of blocking systems over the northern hemisphere on hurricane Katrina, a comparative study among four large hurricanes in the tropical Atlantic region that made landfall, Katrina, Rita, Wilma, and Andrew, was performed. Figure 7 and Table 5 show the tracks, landfall locations, and characteristics of the hurricanes. In addition, the blocking systems over the northern hemisphere were characterized by studying the anomalies of the geopotential height at the 500 hpa level for the periods of each hurricane (Figure 8 and Table 5). The results of this comparative study revealed that during each of the five hurricanes there was a dominant diffluent block over Siberia. These blocks were simultaneously associated with strong westerly air currents over North America. Meanwhile, the northern Atlantic had extreme negative anomalies in the geopotential height values. Comparison of the anomalies at the 500 hpa level shows nearly similar values for hurricanes Katrina and Rita, as is clear from Table 5. For hurricane Wilma, the blocking system was over all of Europe, including Siberia, and the splitting of the westerly air currents occurred over the northeastern coast of the North America, with +200 m anomalies in the 500 hpa geopotential height level. For hurricane Andrew, the splitting of the westerlies occurred over the North Atlantic region, with an extreme in the westerly air current over North America with a mean value of +80 m at the 500 hpa level. Siberia had a diffluent block, with mean values of +100 and -90 m over northern and southern Siberia, respectively. The main feature through the period of hurricane Andrew was an extreme negative anomaly of geopotential height of -200 m over the northern Atlantic region, as is shown in Figure 8 and Table 5.

(a)



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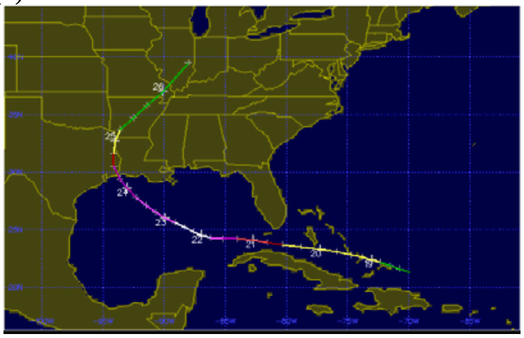

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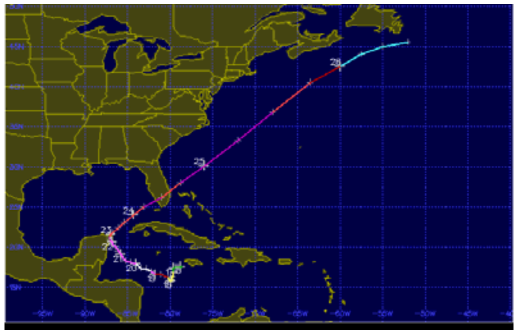

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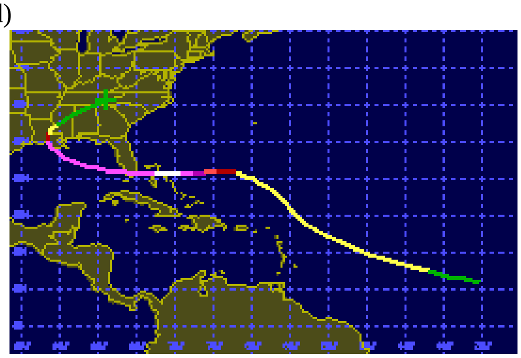


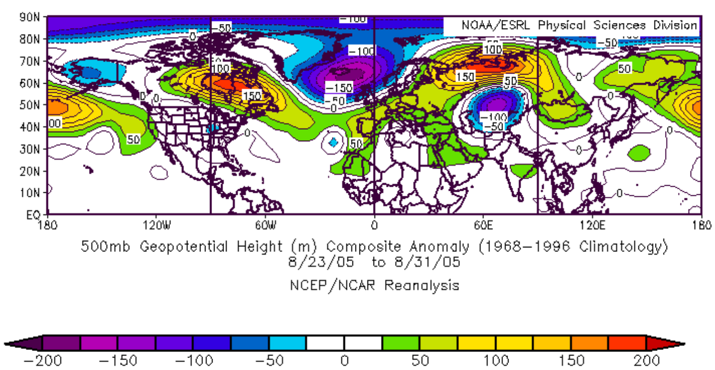
Figure 7: The tracks of the Atlantic hurricanes Katrina, Rita, Wilma, and Andrew.

Table (5): Characteristics of hurricanes Katrina, Rita, Wilma, and Andrew, and the blocking systems over the northern Hemisphere through the duration of each hurricane.

Characteristics of Atlantic Hurricanes and northern blockings / **Name of Hurricane**	**Hurricane characteristics**				**Blocking over the northern hemisphere during the hurricane period**		
	Duration	Category	Maximum wind speed (Knot)	Landfall region	No. of days of blocking over the northern hemisphere	Maximum mean positive anomalies in 500 mb level at northern hemisphere Value and location	Minimum mean negative anomalies in 500 mb level at northern hemisphere Value and location
Katrina	23-31 AUG 2005	5	150	Louisiana	9 days	+200 (m) over North America, +75 (m) over Europe, +200 (m) over north	-200 (m) over North Atlantic , -150 (m) over south Siberia

						Siberia	
Rita	18-26 AUG 2005	5	155	Texas/ Louisiana	8 days (19-26)	+150 (m) over North America, +100 (m) over Europe, +150 (m) over north Siberia	-125(m) over North Atlantic, -50 (m) over south Siberia
Wilma	15-26 OCT 2005	5	160	Florida	9 days (18-26)	+200 (m) over North America, + 75 (m) over Europe, +100 (m) over north Siberia	-150 (m) over North Atlantic, -50 (m) over south Siberia
Andrew	16-28 AUG 1992	5	150	Florida, Texas, Louisiana	7 days (22-28)	+80 (m) over North America, +100 (m) over Europe, +100 (m) over north Siberia	-200 (m) over North Atlantic, -90 (m) over south Siberia

(a)



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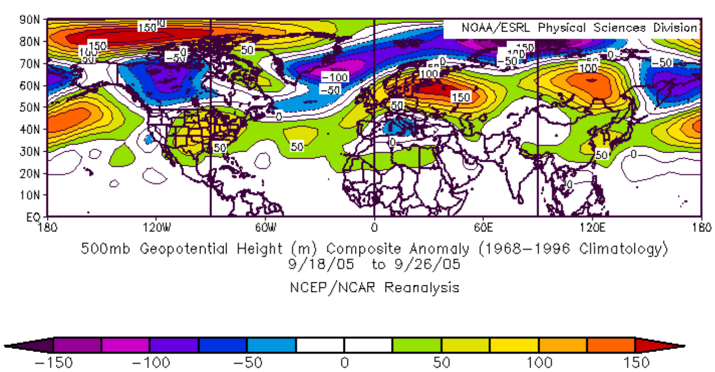

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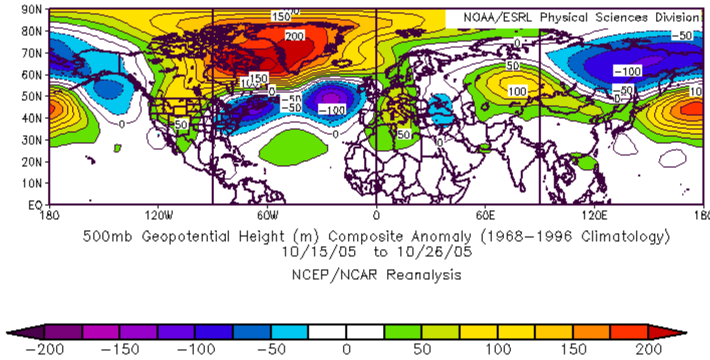

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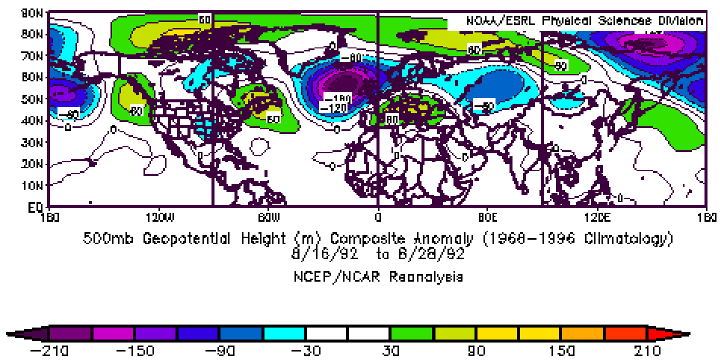

Figure 8: The distribution of the 500 mb geopotential height (m) composites anomaly in the northern hemisphere. (a) for Hurricane Katrina 23-31 Aug., 2005.(b) for Hurricane Rita 18-26 Sep., 2005. (c) for Hurricane Wilma 15-26 Oct., 2005, and (d) for Hurricane Andrew 16-28 Aug., 1992.

5. Discussion and Conclusion

The diffluent block system that persisted over Siberia prevented the large westerly air currents aloft that existed over North America from crossing the Atlantic Ocean toward Europe. The air current persisted over North America. This persistence of the two pressure systems over Siberia and North America generated a splitting of the westerly air currents over the Atlantic Ocean into two distinct branches. The first branch moved northward towards the northern Atlantic Ocean, while the second went southward and generated abnormal northeast to east air currents over the tropical Atlantic region. The Gulf of Mexico was thus under the influence of two abnormally strong winds. First, there existed strong east-northeast winds in the tropical Atlantic. Second, there were strong south winds in the southeastern part of North America. These two winds put the Gulf of Mexico under the torque force of winds, which accelerated the circulation of hurricane Katrina, controlling its track through the Gulf of Mexico and changing the track from south to the north toward land, leading to landfall in Gulfport. The results revealed that there are significant correlations between the anomalies in the geopotential height at the 500 mb level over North America and Siberia, and the precipitation rates in the tropical Atlantic and eastern North America. In addition, there is a significant correlation between the anomalies in the geopotential height at the 500 mb level over northern Siberia and the anomalies in the meridional winds over the tropical Atlantic region and eastern part of North America. One can conclude that the blocking systems over the northern hemisphere through the period of 22-31 August 2005 controlled the power and track of hurricane Katrina.

A comparative study of four large hurricanes in the tropical Atlantic region, which all made landfall (Katrina, Rita, Wilma and Andrew), was performed. All four hurricanes caused widespread damage. The results from this study show that during each hurricane, a diffluent block existed over Siberia, accompanied by strong westerly air currents aloft above North America. The splitting of the westerly air currents that occurred over the northern Atlantic regain was dominant. From the present study, one can conclude that the strong westerly air current aloft over North America *must have been prevented* from crossing the Atlantic ocean and were blocked by the diffluent block over Europe or Siberia, which controlled and forced the tracks of the tropical Atlantic hurricanes towards landfall in the southeastern USA by adding abnormal northeast–east air currents to the tropical Atlantic region.

Acknowledgments

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